Fourth Quarterly Progress Report
IITRI Project No. M272, Phase III

STUDIES OF LUNAR AND MARTIAN SOIL MECHANICS

by

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December 31, 1965

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for

National Aeronautics and Space Administration
Structures and Operations Problem Group
Space Vehicles Division
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I. INTRODUCTION

This is the fourth quarterly report on Phase III of Project NASr-65(02), "Studies of Lunar and Martian Soil Mechanics". Phase III was initiated on December 15, 1964 and this report covers the period from September 15, 1965 to December 15, 1965.

The principal purpose of the program as outlined in IITRI Proposal No. 65-183M, entitled "Studies of Lunar and Martian Soil Mechanics" is to measure the effects of the lunar and Martian environments on the physical properties of simulated soils. In the study of lunar soils it has become increasingly clear that the most serious problem is obtaining "clean" particles, a condition which must certainly exist on the lunar surface after such long exposure to the ultra-high vacuum environment. Even though elaborate schemes might be employed in the laboratory to produce "clean" particles, there is still no satisfactory means of measuring the degree of "cleanliness" attained. The approach taken in this present study is to evaluate the effect of degree of "cleanliness" on the physical properties by measuring the properties as a function of the amount of gas desorbed from the particle surfaces.

II. COMPOSITION OF ADSORBED GAS

Experiments are presently being performed to determine the composition of the gas layers adsorbed on the soil particles. The apparatus being used in these experiments was described in a previous quarterly report.[1/] It consists of a small container

[1/] Vey, E. and J. D. Nelson, "Studies of Lunar and Martian Soil Mechanics", Second Quarterly Progress Report, IITRI Project M272-III, June 30, 1965.

fabricated from thin tantalum sheet into which the soil is placed and through which low voltage alternating current is passed to heat the sample. The maximum temperature obtainable is approximately 900°C. The container is closed except for a small opening facing the inlet port of an ultra-high vacuum, mass spectrometer type, residual gas analyzer. Thus, the desorbed gas issues from the opening in the form of a molecular beam which impinges on the mass spectrometer.

Experiments were first performed using the empty container in order to determine the spectrum of the background residual gas and its reproducibility. The system was pumped down and scans made at various temperatures. The container was allowed to cool and the system purged with dry nitrogen and allowed to remain open to the atmosphere for approximately one hour. It was then pumped down again and the procedure repeated. This simulated the time required to fill the container with soil and to ascertain the background spectrum after the container had been "cleaned" during the dry run and subsequently contaminated during the filling operation.

Peak values of typical residual gas spectra determined at ambient temperature and at 650°C are shown in Fig. 1 and 2. All three scans were quite similar indicating that during the period in which the vacuum chamber was open, gas was readsorbed on the container of approximately the same amount and composition each time.

Experiments were then performed in which the container was filled with quartz powder. The temperature of the soil was increased in increments of approximately 100°C and a scan was made at each temperature level. The major peaks observed are shown in Fig. 3 through 9. In Fig. 3 and 4 the results of two scans are shown; one scan was taken approximately five minutes after raising the temperature and the second after a period of approximately 15 to 30 minutes. The shaded portions represent the differences between the peak heights obtained with and without soil in the container and, hence, are indicative of the quantity of the different gases being desorbed from the soil. By comparing the different figures it can be seen that a relatively small quantity of gas was removed at temperatures less than approximately 200°C but at temperatures of this magnitude or greater a substantial quantity of gas was desorbed and the amount increased to a maximum at approximately 300°C. A further increase in temperature resulted in the removal of an additional but smaller amount of gas.

Noting that the partial pressures are plotted on a logarithmic scale it can be seen that the primary constituent was of mass 2. This, together with the high peak at mass 18 suggests that most of the desorbed gas was undoubtedly water. The peaks at 28 and 44 are probably due to nitrogen, carbon dioxide and possibly some carbon monoxide.

Similar experiments were performed on olivine powder. In these experiments considerably more gas was desorbed from the sample than from the quartz and, hence, while the quartz could be heated to the maximum temperature in 100°C increments within a period of eight hours it was necessary to increase the temperature of the olivine in smaller increments to allow it to remain at these temperatures for a longer period of time. Consequently, over four days were required to complete one test.

Typical results of the scans taken on the olivine are shown in Fig. 10 through 13. The background shown in these figures is the same as that used for the quartz. However, because of the longer periods of time during which the elevated temperatures were maintained it is expected that the background peaks shown are only upper bounds and the actual amount of gas from the container and surrounding system was probably considerably less, particularly at the higher temperatures.

It can be seen that although the quantity of gas removed from the olivine is considerably greater than for the quartz the major peaks occur at the same mass numbers. This would indicate that the previously observed difference in vacuum effects on the olivine and quartz powders was primarily due to a much larger amount of gas adsorbed on the olivine and, hence, after the same pumpdown procedure for each material the surfaces of the olivine particles were considerably more contaminated.

It may be noted that in Fig. 13 the background peaks are larger than for the container filled with soil. This is undoubtedly due to the fact that the container had been "cleaned" much more thoroughly during the experiment on the olivine than it was when the background was measured previously. A more accurate determination of the residual gas in the empty system is necessary, therefore, before final conclusions can be drawn.

It appears, however, that the major constituent of the gas removed was water vapor. In the case of olivine it is possible that some of this water vapor could have been derived from the crystal structure through replacement of the desorbed gas on the particle surfaces.

III. GENERATION OF CLEAN PARTICLE SURFACES

During the experiments to determine the composition of desorbed gas, the pressure in the chamber was monitored and is shown as a function of time in Fig. 14. Following the first experiment on quartz powder the container was emptied and the temperature-time history was repeated. The resulting pumpdown curve is also shown.

For the empty container, when the temperature was increased the pressure rose sharply and then dropped off, very rapidly at the lower temperatures but more slowly at higher temperatures. It is believed that the slower drop in pressure at the higher temperatures was due to the chamber walls nearby having been heated somewhat by radiation from the container thereby contributing to the gas load.

For the case when the container was filled with soil the pressure also increased when the temperature was increased but did not drop rapidly. For the lower temperatures it leveled off at an increased pressure until a temperature of 400°C was reached.

At temperatures greater than 400°C the pressure dropped more rapidly after the initial increase and for higher temperatures the initial peak pressure was less than for the previous one. The dashed portion of the curve at 200°C represents a short period during which the power was turned off and the soil was allowed to cool. The difference between the two curves represents the amount of gas which was desorbed from the soil during heating and pumpdown.

This experiment was repeated using a different sample but after the maximum temperature had been reached and maintained for approximately one hour the container was allowed to cool over night and the same procedure repeated on the second day. On the third day the maximum temperature was attained within the first hour and was maintained for a period of five hours. The results of these experiments are shown in Fig. 15.

It can be seen that on the second day, increases in temperature to 620°C caused only very small increases in pressure. At the maximum temperature (760°C) the pressure rose to a level close to that at which it had begun to level off the previous day. The same was true for the third day. The difference between these curves then indicates the quantity of gas removed from the soil, container and neighboring portions of the chamber which was not readsorbed during the cooling period. It is evident that elevated temperatures are quite effective in outgassing the soil and are very necessary in order to achieve clean particle surfaces. It is also evident that almost all of the gas that was desorbed was removed from the system by pumping, leaving very little to be readsorbed upon cooling.

Results of experiments on olivine are shown in Fig. 16. The different scales on the abscissae of Fig. 15 and 16 should be noted. As mentioned previously it was necessary to increase the temperature in smaller increments in this experiment and to maintain each temperature for a longer period of time. At the higher temperatures, however, the length of time necessary before the temperature could be increased further at each increment decreased as well as the peak pressure. After the maximum temperature had been reached and the sample allowed to cool overnight, the temperature could be increased to the maximum again within a period of eight hours with only small rises in the pressure. This again shows the quantity of gas removed from the system that was not readsorbed. Comparison of Fig. 16 with Fig. 14 and 15 indicates the difference between the quantity of gas desorbed from the olivine and the quartz. As was stated previously, this would account largely for the difference in vacuum effects between the two materials.

In all previous experiments on the mechanical properties of soils under vacuum, the changes in soil properties were related to the vacuum levels at which the experiments were performed. Although it was recognized that the particle surfaces were not "clean" the actual amount of gas remaining on the surfaces was not known. In order to investigate the effect of various degrees of cleanliness on the shear strength of soils, experiments are planned in which a small container of soil will be heated and the pressure monitored as a function of time to obtain a measure of the quantity of gas desorbed. The penetration resistance will then be measured by a penetrometer at various temperatures and time periods to determine the penetration resistance as a function of the quantity of desorbed gas.

In these experiments it will be desirable to use the smallest allowable soil sample in order to facilitate outgassing. Consequently, experiments were performed to determine the optimum size of penetrometer and the minimum size of container for which boundary effects would be negligible.

Penetrometer experiments were first performed in a container 10 in. in diameter and 7.3 in. deep at various distances from the penetrometer centerline to the edge of the container ranging from 5 to 0.5 in. The sizes of penetrometers selected were 0.75, 0.50 and 0.25 in. in diameter. The penetration resistance for the three different penetrometers at various edge distances is shown in Fig. 17 to 19. While very small distances from the edge had a small effect on the shape of the curve, reproducible data were difficult to obtain using the 0.25 in. penetrometer. Experiments were then performed using the three penetrometers and containers having depths of 3.0, 2.0 and 1.5 in. The results of these experiments are shown in Fig. 20 through 22. As may be seen from Fig. 19 and 22 the 0.25 in. penetrometer provided data which was not very reproducible. This is most probably due to nonhomogeneity in the soil density and the small cross sectional area necessitating the measurement of very small loads. From Fig. 20 and 21 it can be seen that the 0.50 in. penetrometer will permit a greater penetration before the container effects become noticeable than will the 0.75 in. penetrometer.

Consequently, a 0.50 in. penetrometer will be used with a container 3.0 in. in diameter and 2.0 in. deep. This arrangement should permit six penetration experiments to be performed on each sample with a minimum of container boundary effects.

IV. MARTIAN SOIL EXPERIMENTS

Efforts on Martian soil mechanics have thus far been devoted to preparing samples and setting up equipment for experiments on representative Martian soils under Martian environmental conditions.

Samples of limonite have been obtained in powdered and rock form and equipment is currently being devised to enable the grinding of the rock in a gas consisting primarily of carbon dioxide (approximately 66%), nitrogen (approximately 33%) and Argon (approximately 1%).

Dynamic penetration experiments will be performed on both samples under a rough vacuum of approximately 4 to 9 mm Hg. These experiments have not begun at present but will be initiated when the instrumentation and equipment have been completed.

V. PLANNED RESEARCH FOR THE NEXT QUARTER

The work to be carried out in the remaining quarter will closely follow that outlined in IITRI Proposal No. 65-183M, "Studies of Lunar and Martian Soil Mechanics". The schedule for the next quarter is as follows:

1. Direct shear tests on enstatite and obsidian powders in vacuum at various temperatures.
2. Dynamic penetration tests on enstatite and obsidian powders at varying vacuum levels and porosities.
3. Determination of the composition of adsorbed gas.
4. Generation of clean particle surfaces.
5. Martian soil experiments.

VI. CONTRIBUTING PERSONNEL

The following personnel contributed to the work described in the present program.

E. Vey was project engineer.

J. D. Nelson was responsible for the experimental work and analysis of the data.

A. Kirch was in charge of the vacuum facilities and residual gas analysis.

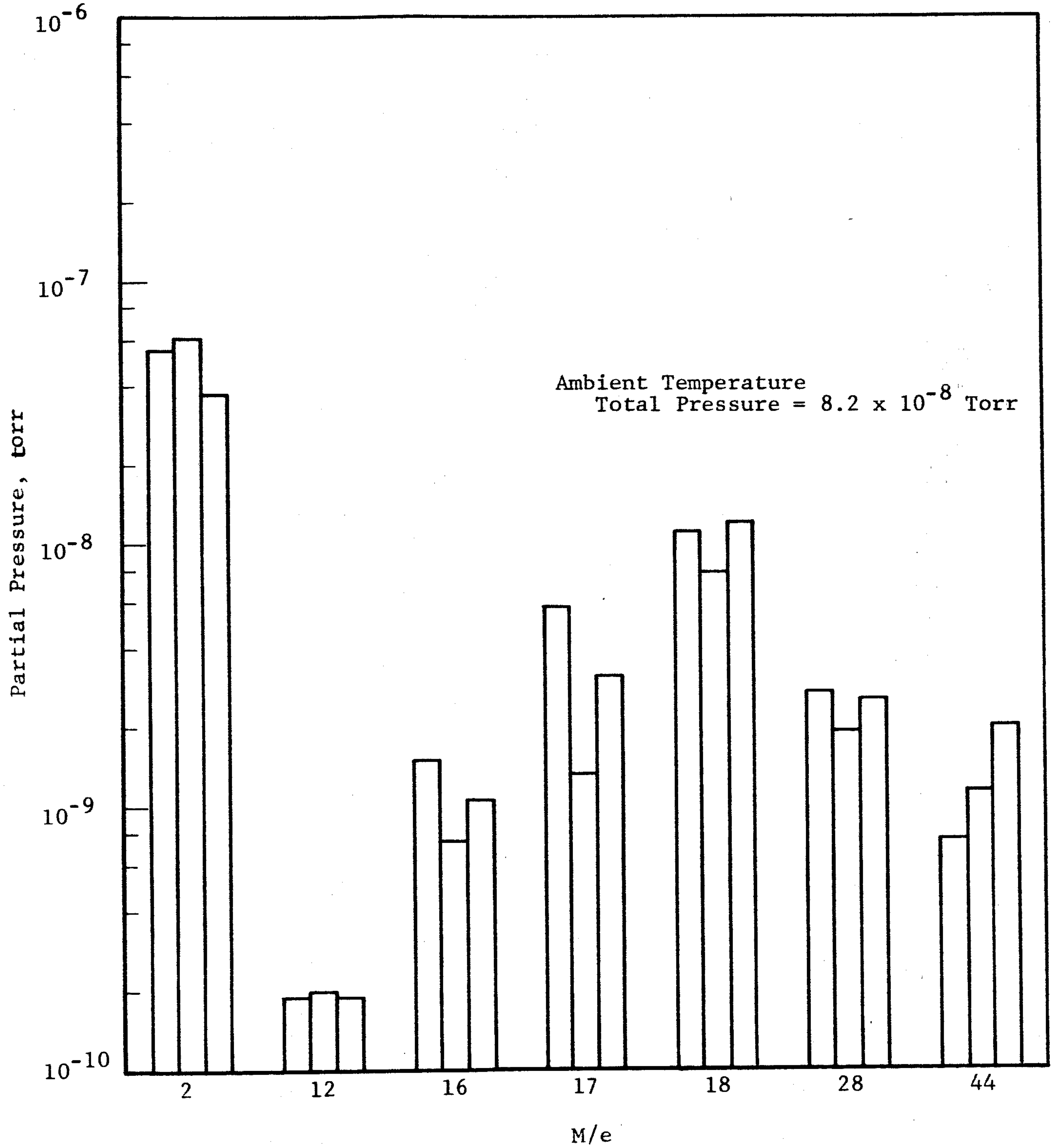

Fig. 1 - BACKGROUND RESIDUAL GAS SPECTRUM

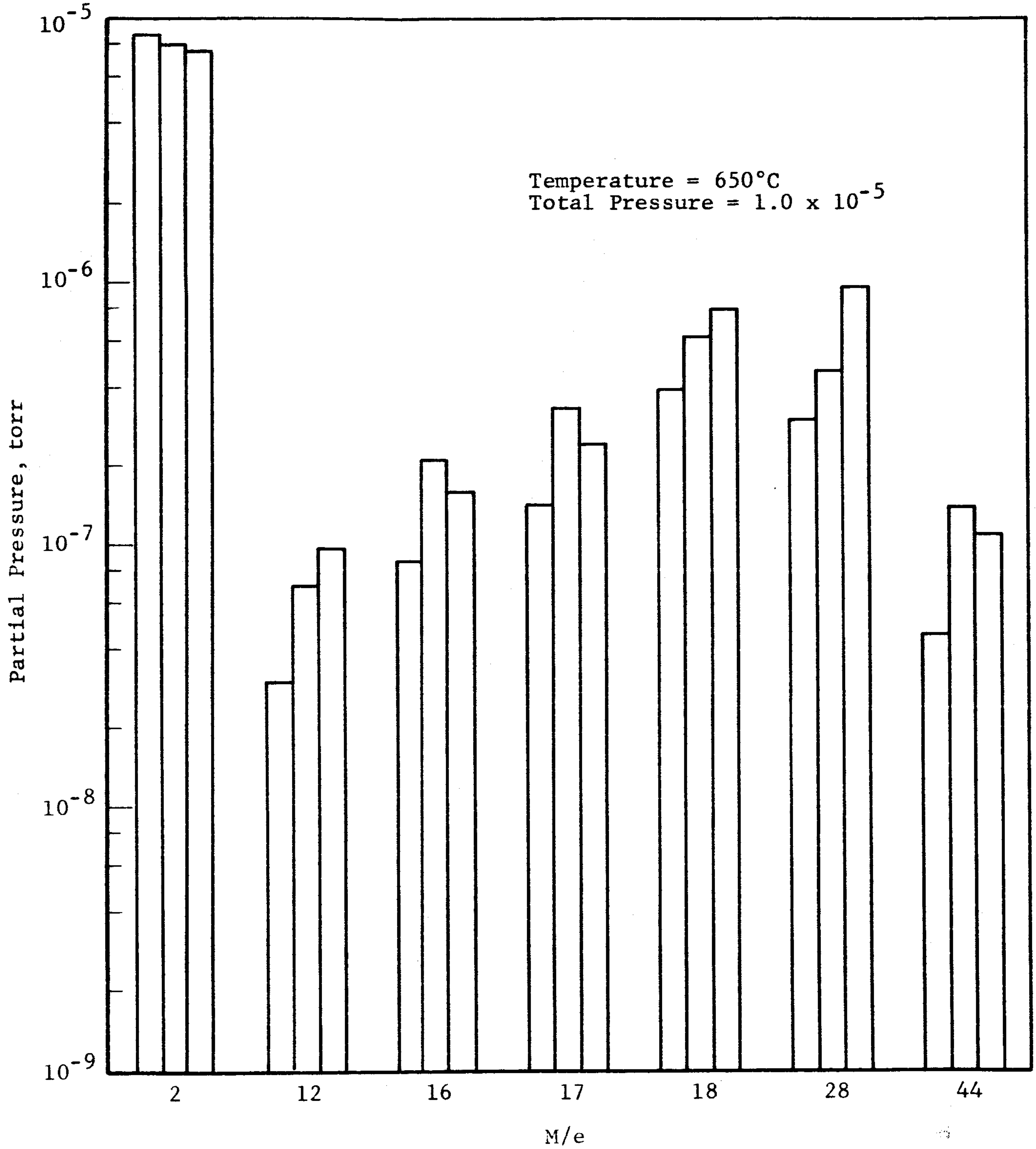

Fig. 2 - BACKGROUND RESIDUAL GAS SPECTRUM

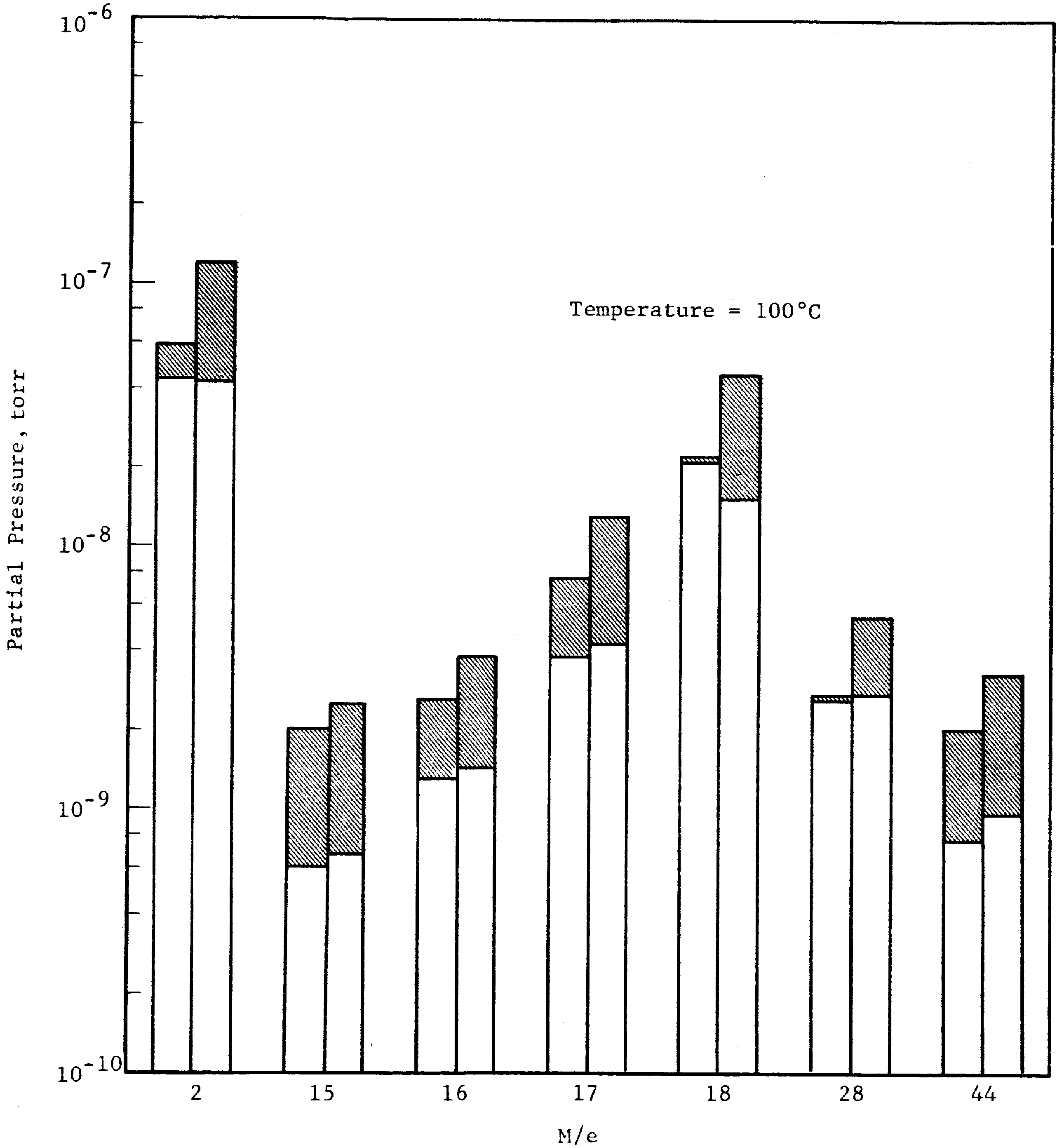

Fig. 3 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

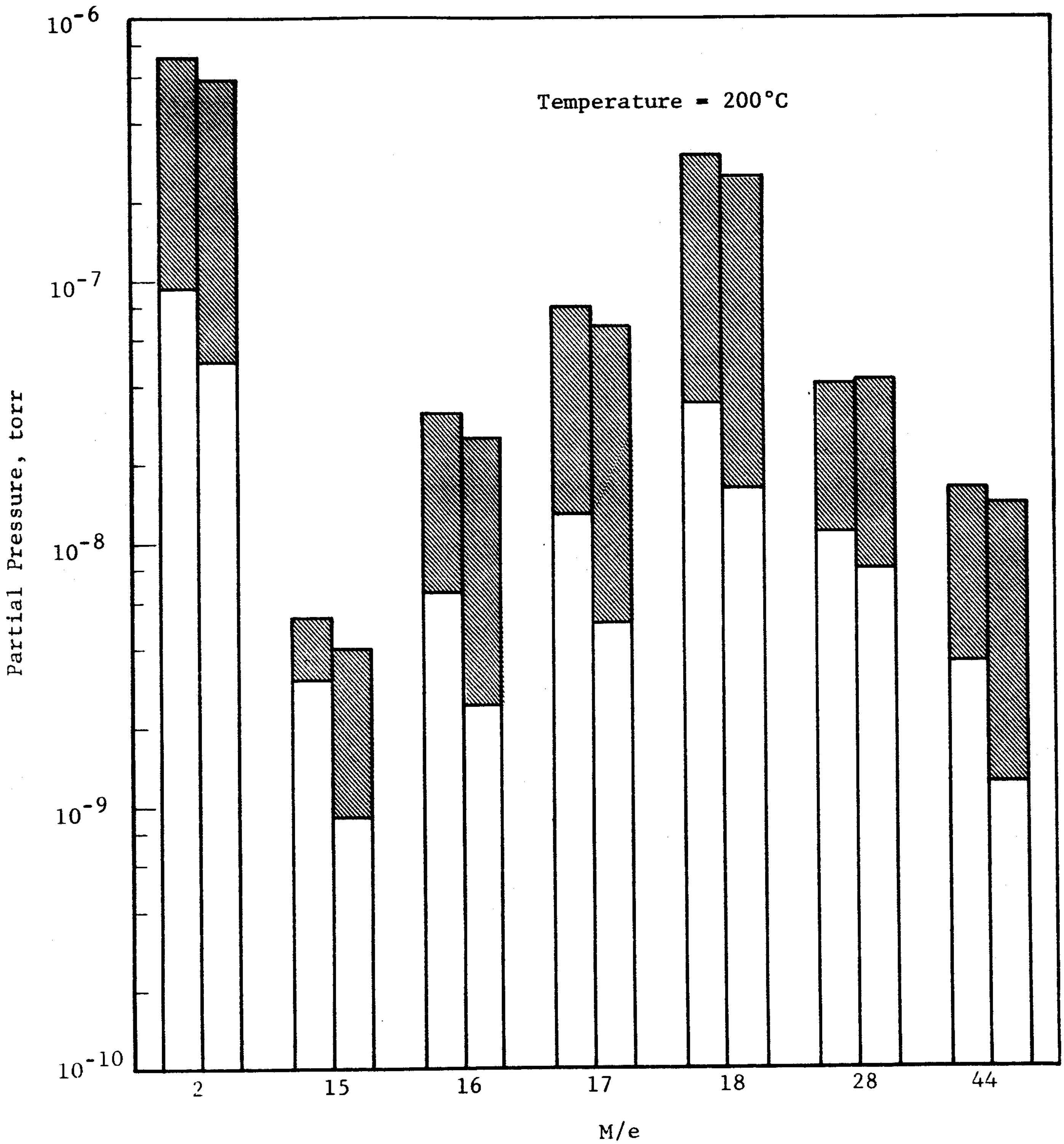

Fig. 4 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

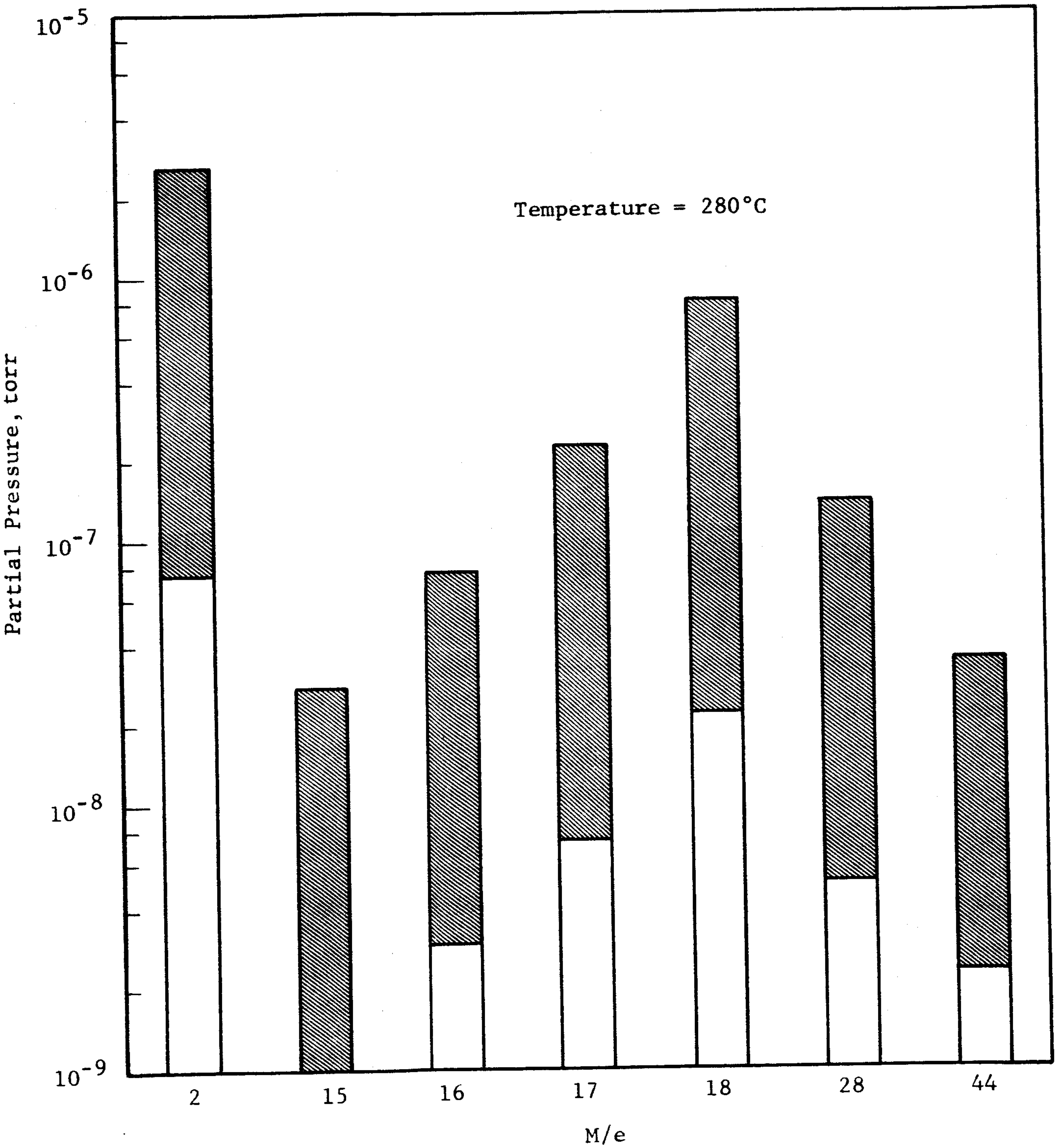

Fig. 5 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

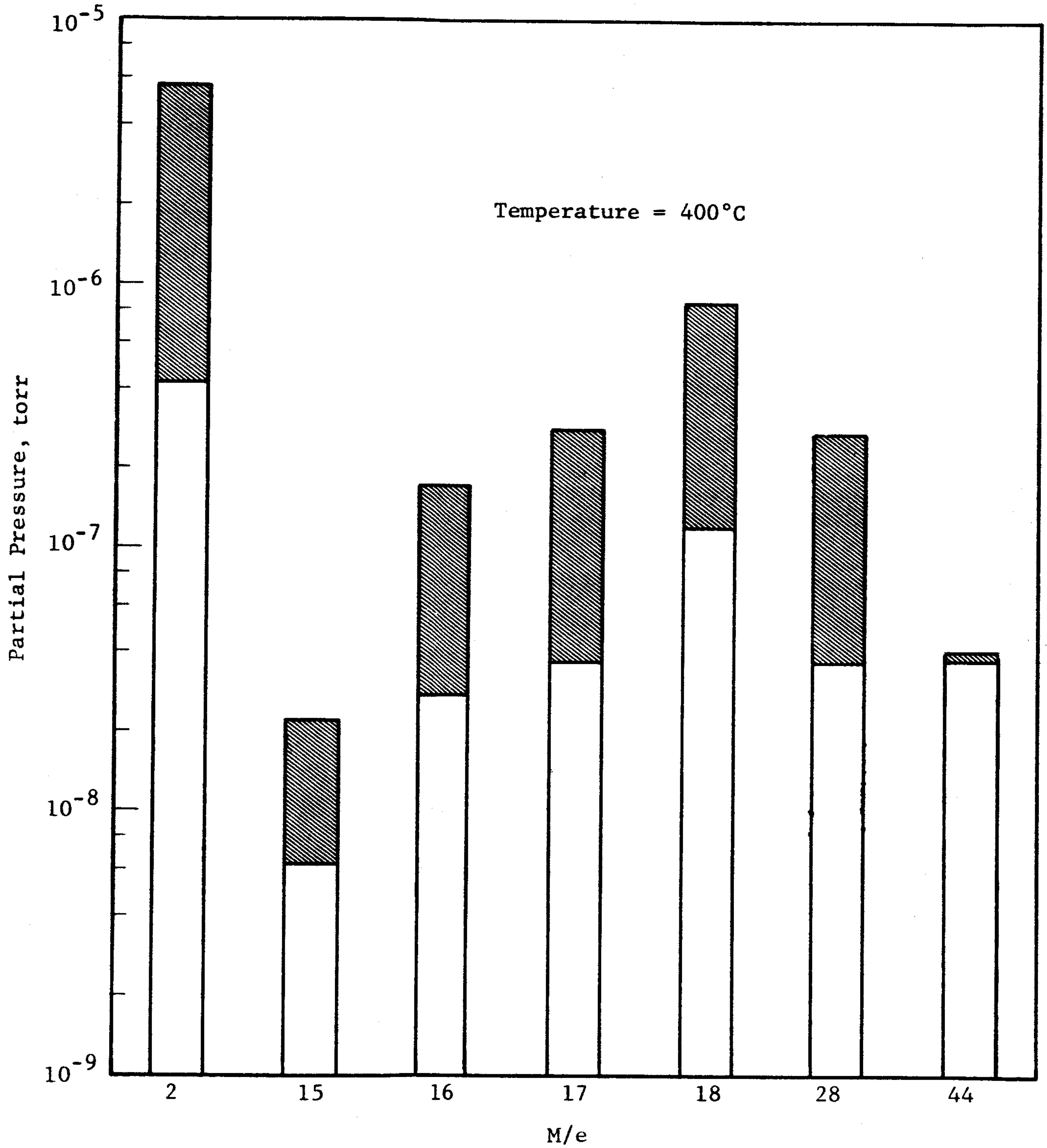

Fig. 6 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

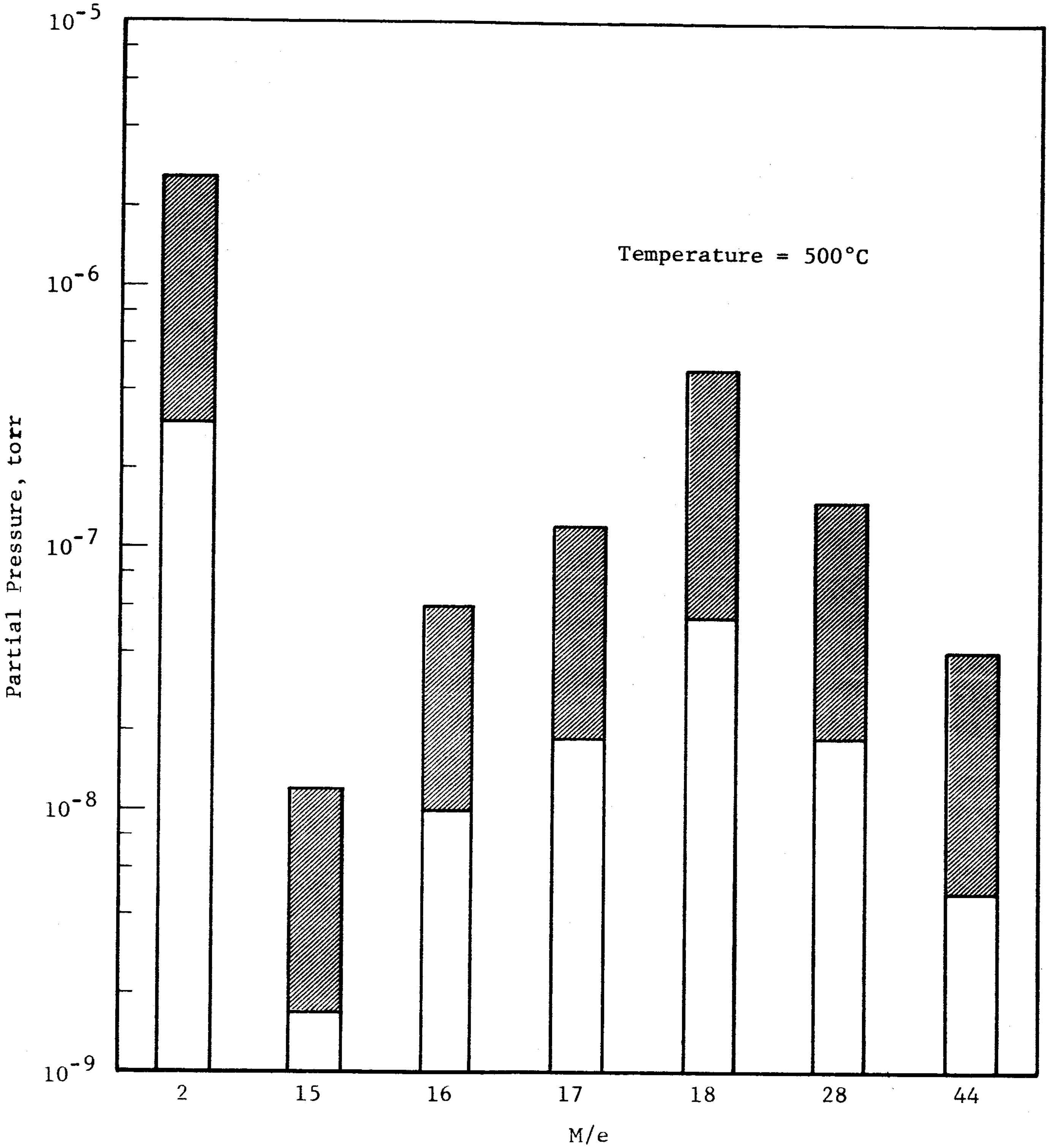

Fig. 7 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

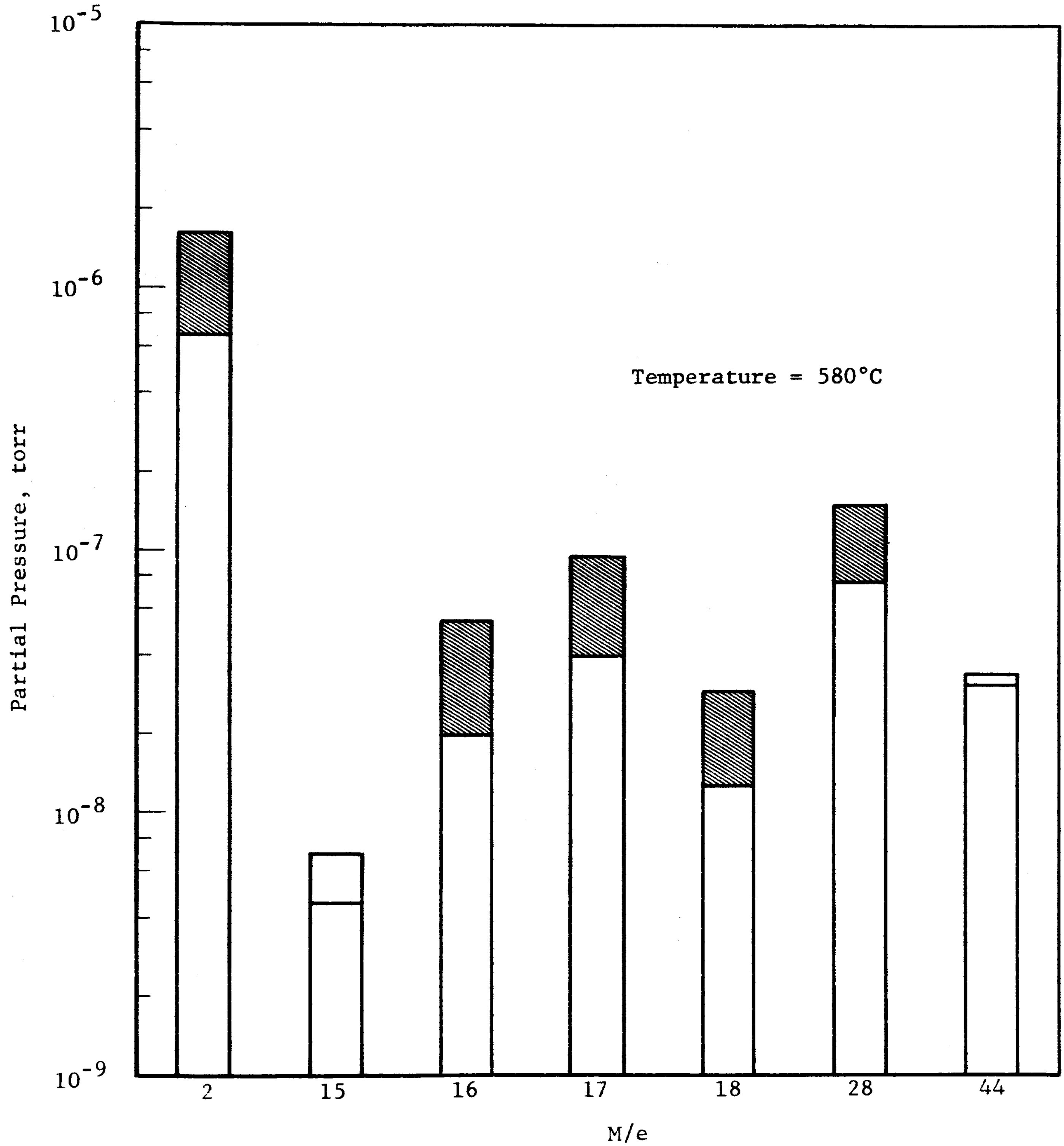

Fig. 8 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

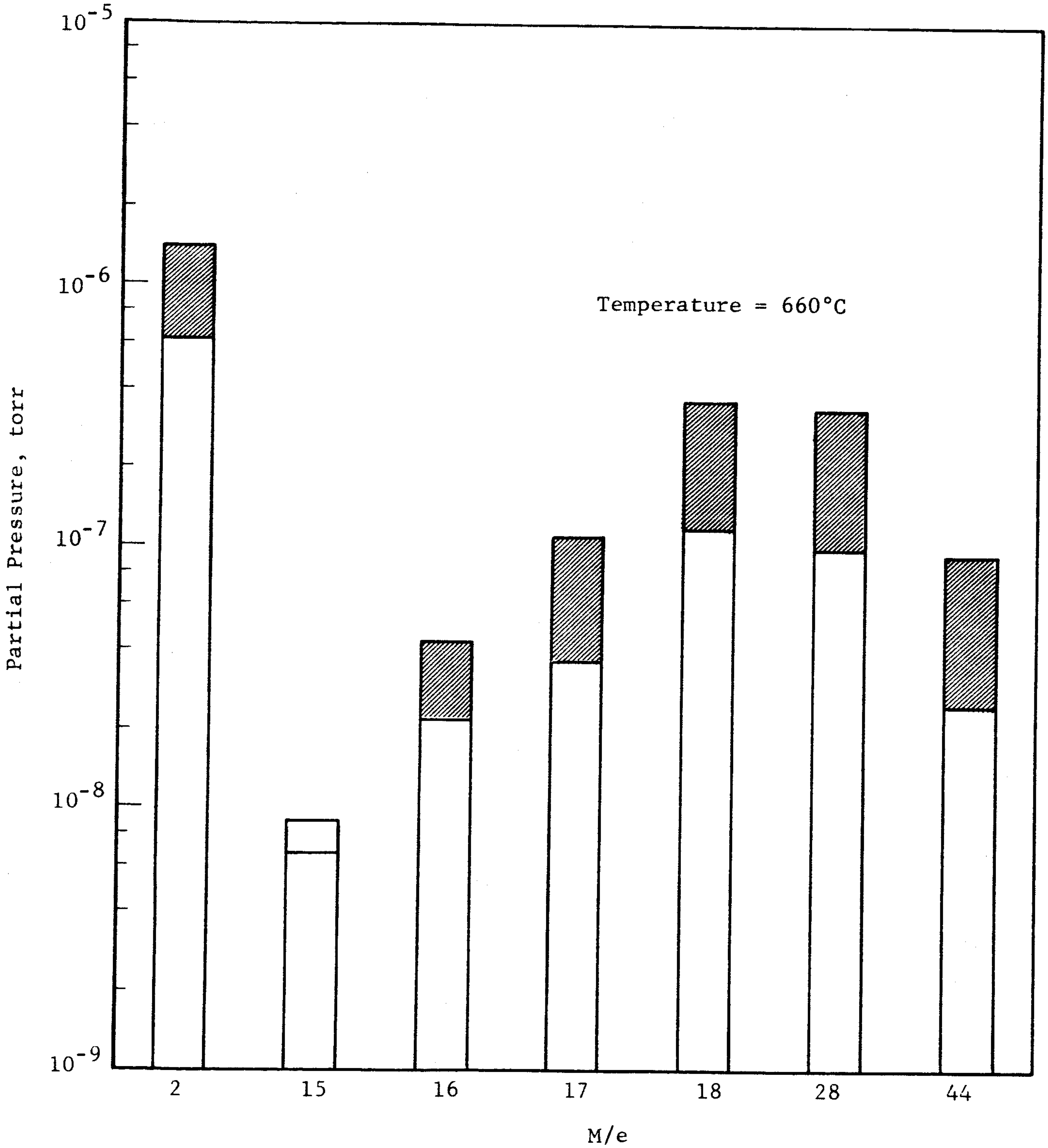

Fig. 9 - DESORBED GAS SPECTRUM FOR QUARTZ POWDER

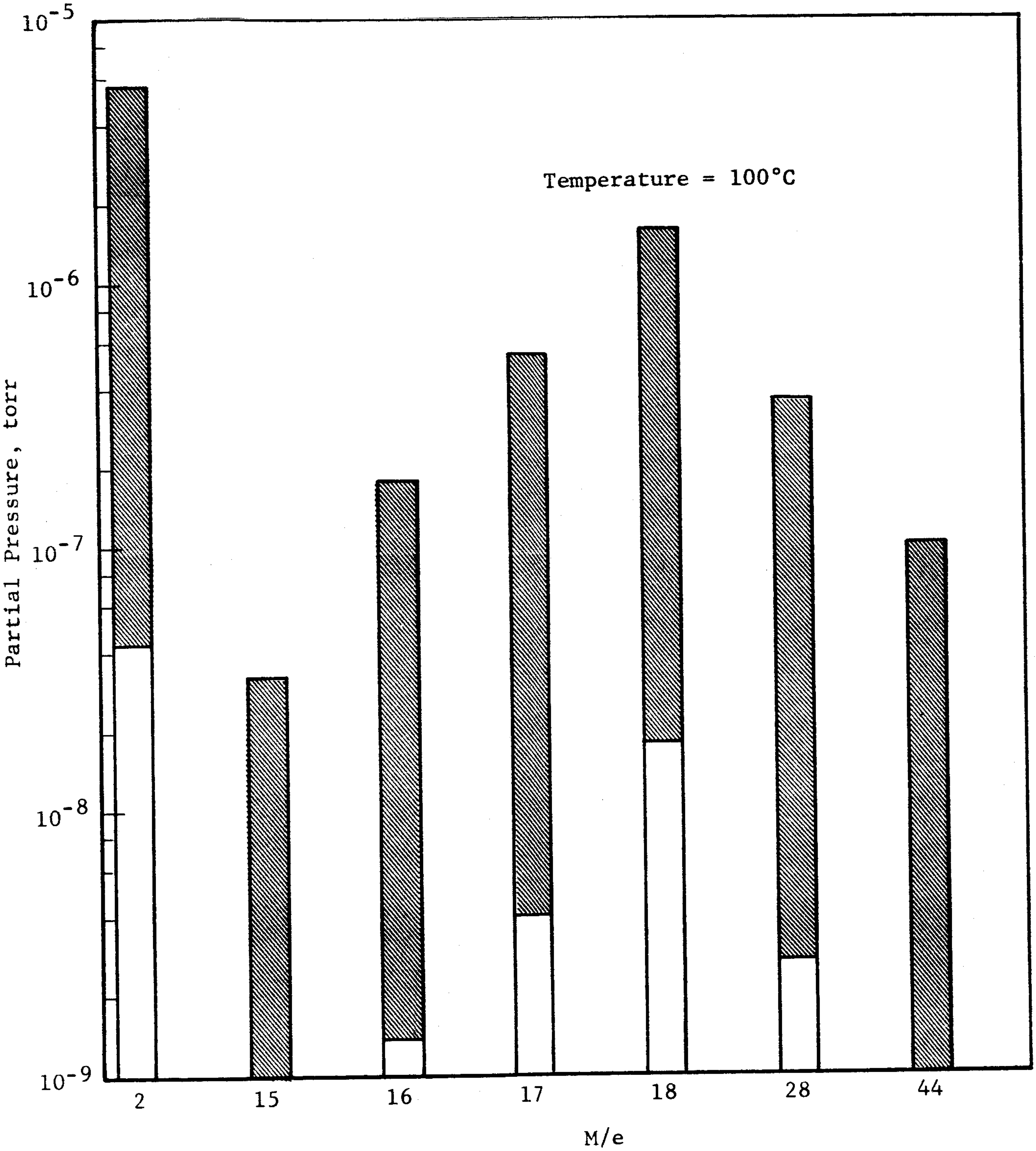

Fig. 10 - DESORBED GAS SPECTRUM FOR OLIVINE POWDER

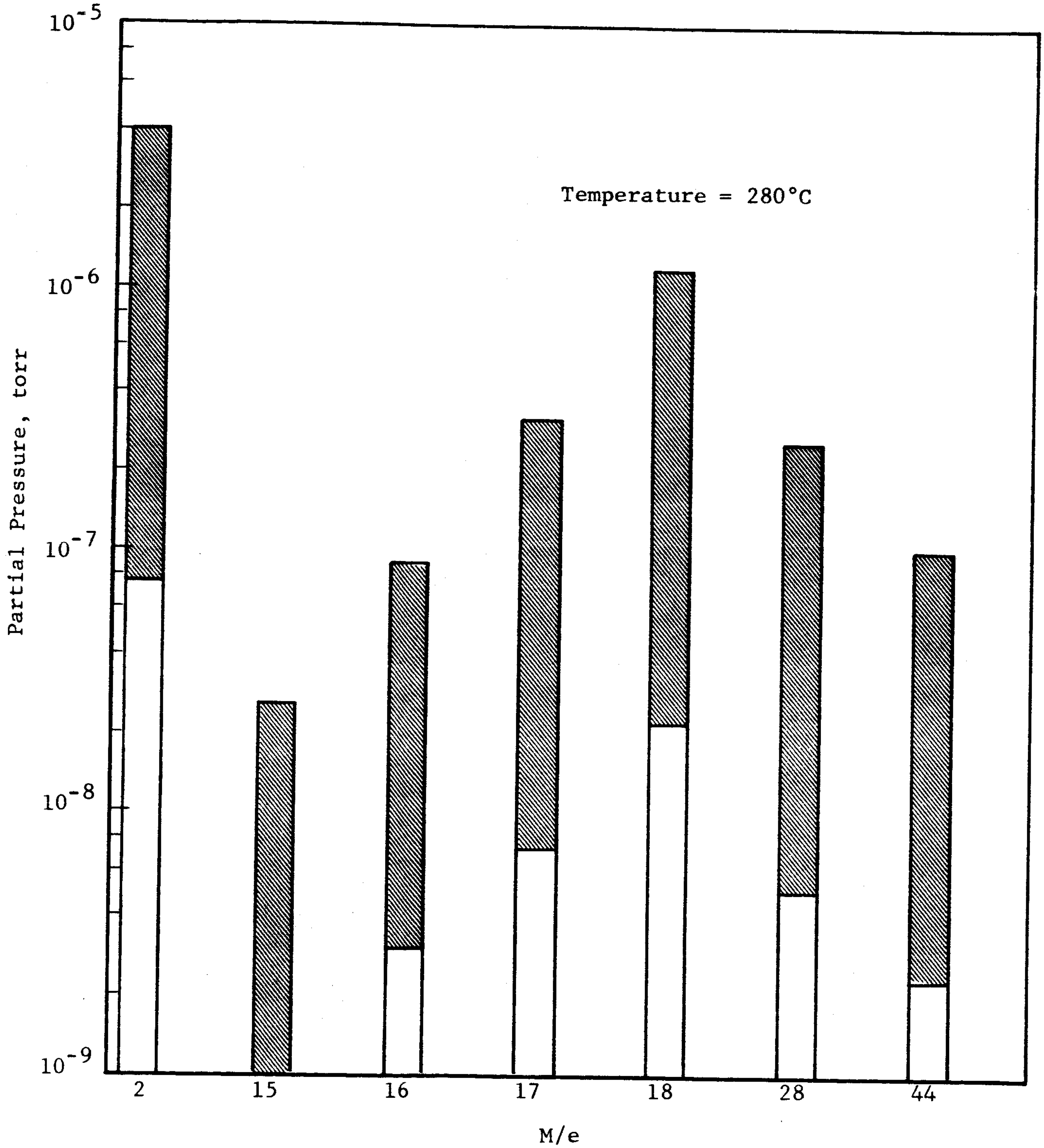

Fig. 11 - DESORBED GAS SPECTRUM FOR OLIVINE POWDER

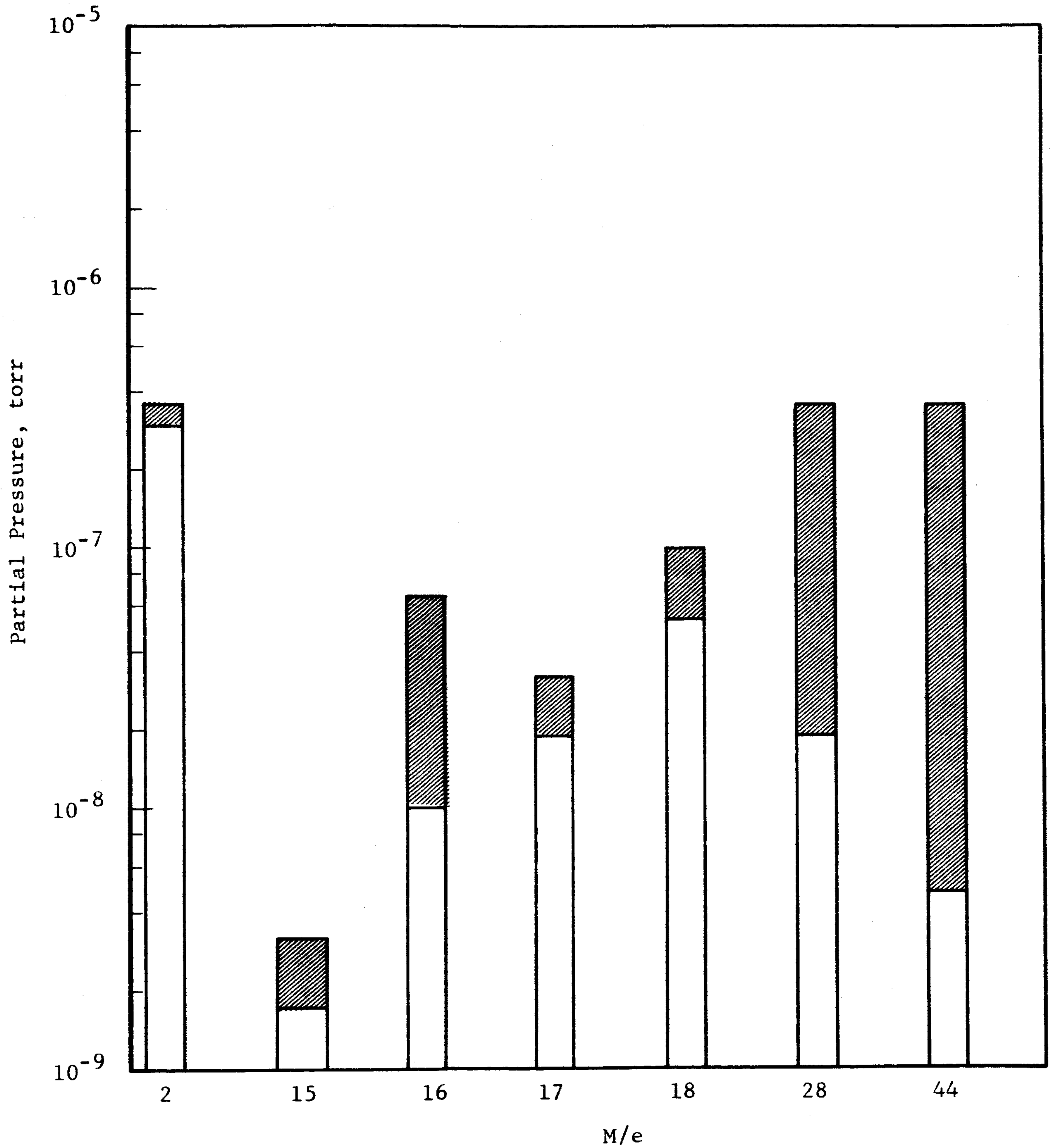

Fig. 12 - DESORBED GAS SPECTRUM FOR OLIVINE POWDER

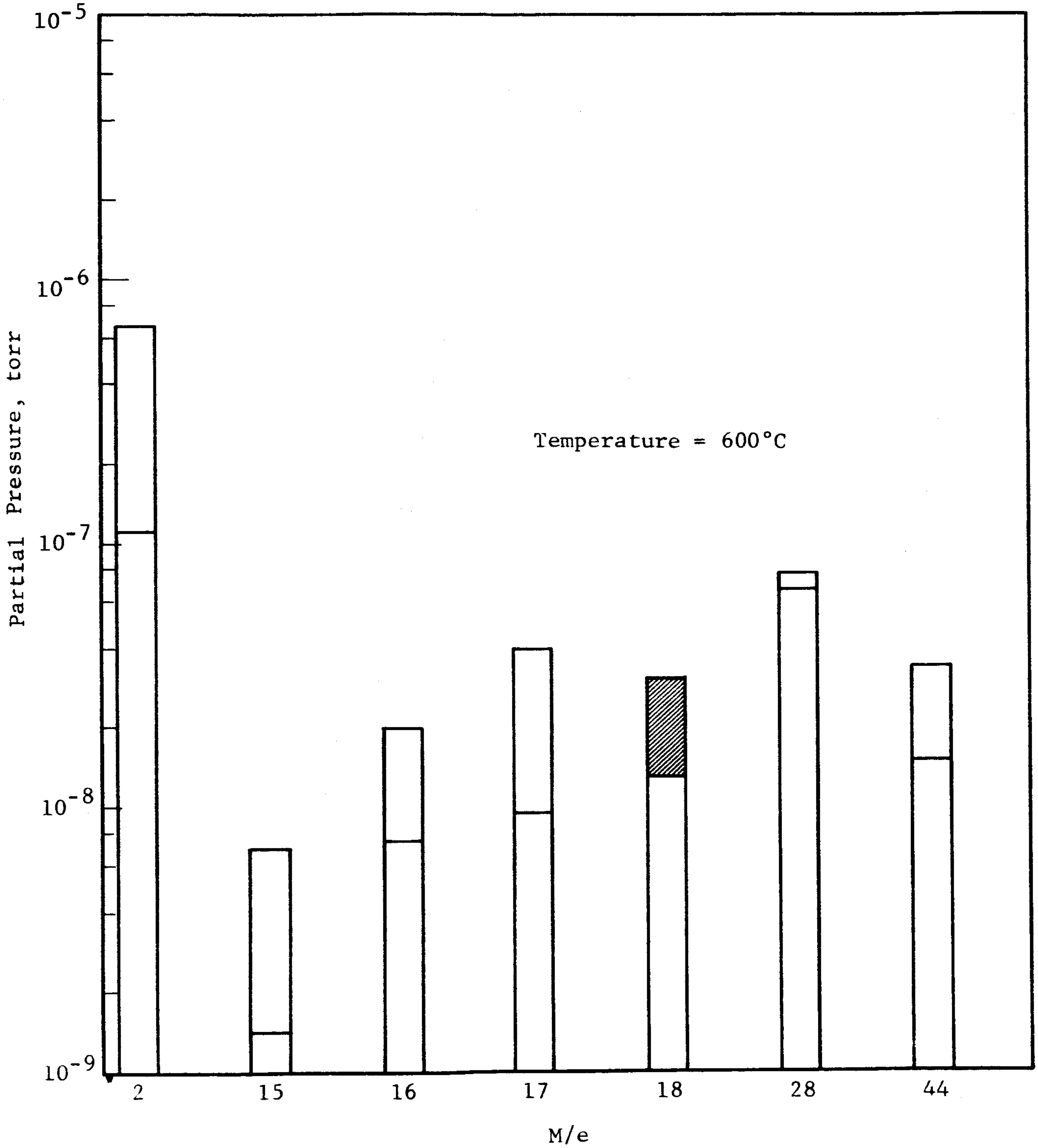

Fig. 13 - DESORBED GAS SPECTRUM FOR OLIVINE POWDER

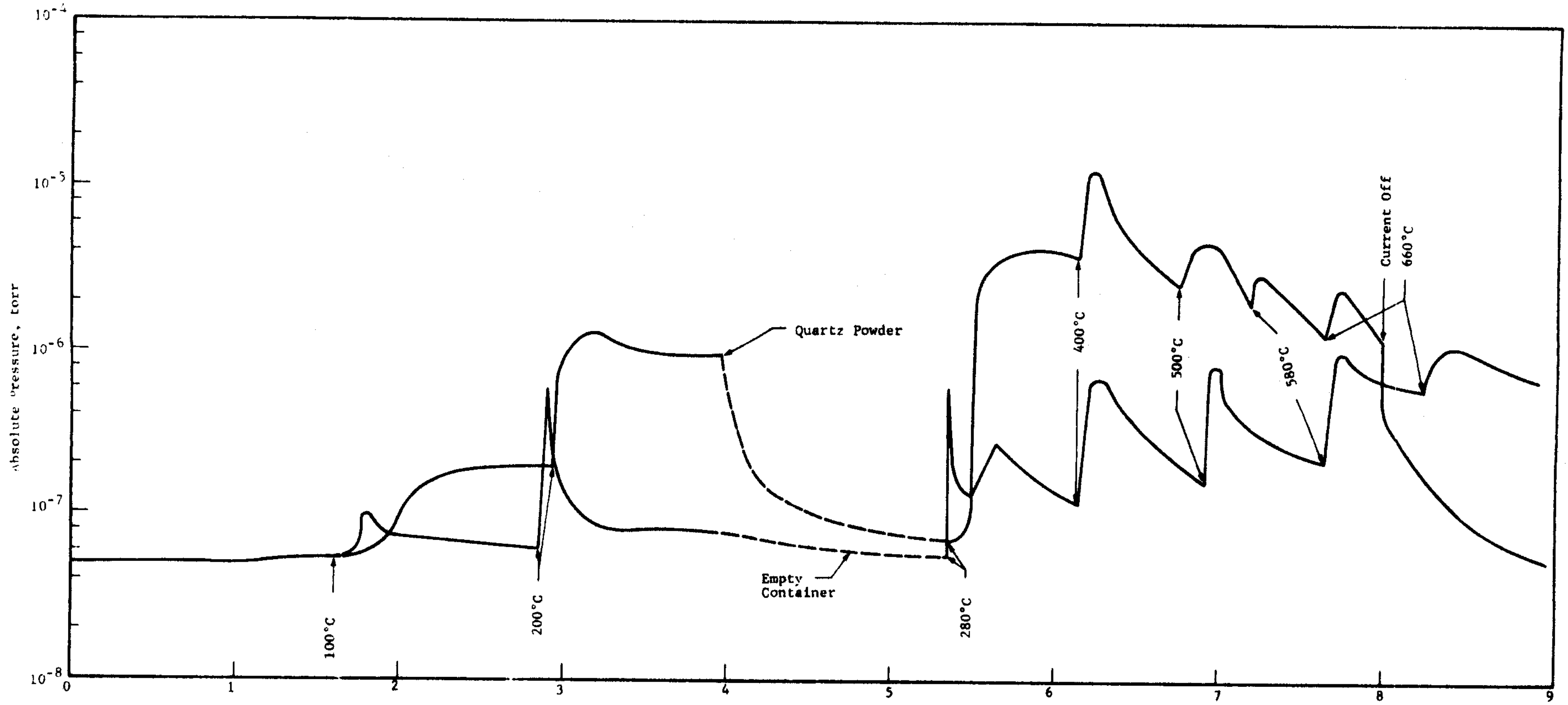

Fig. 14 - PUMPDOWN CURVE FOR QUARTZ POWDER

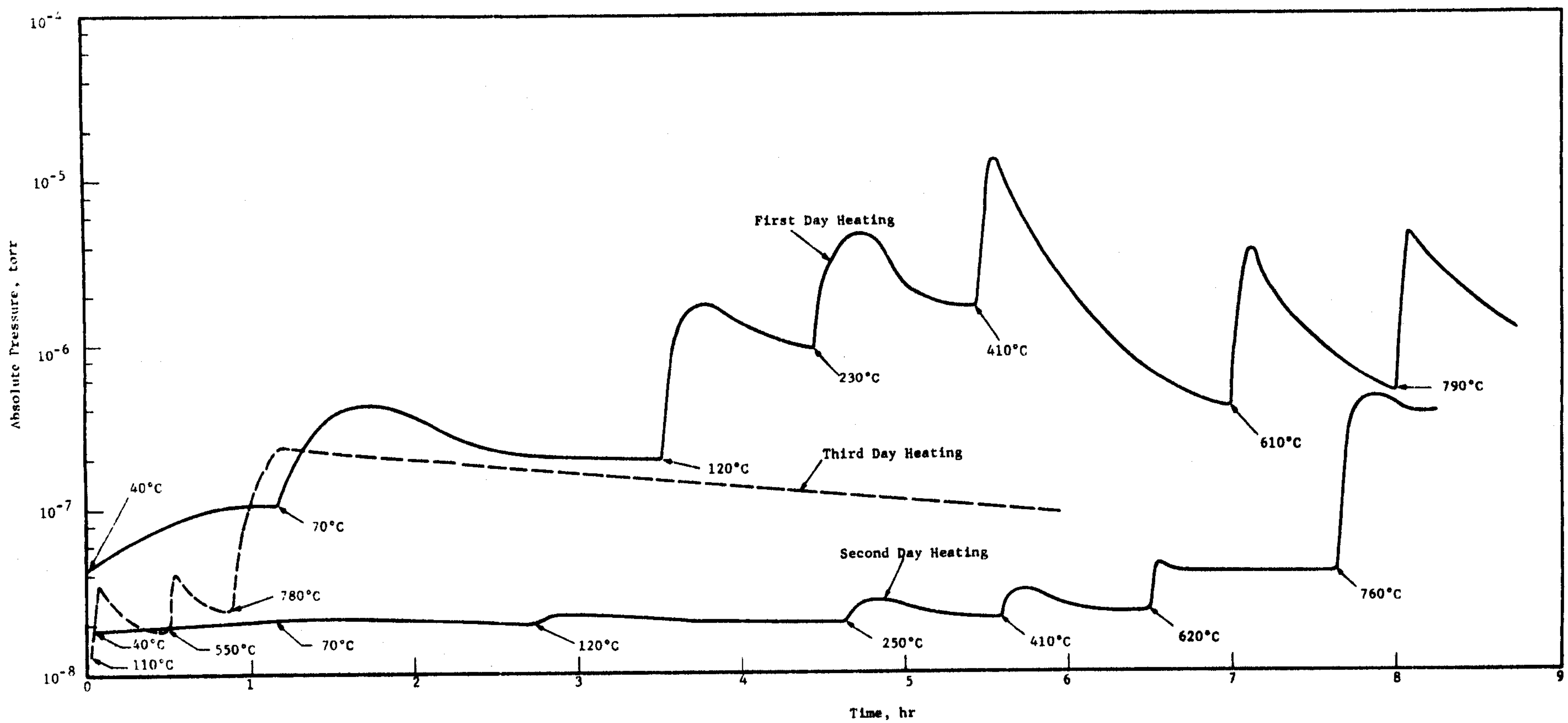

Fig. 15 - PUMPDOWN CURVES FOR QUARTZ POWDER

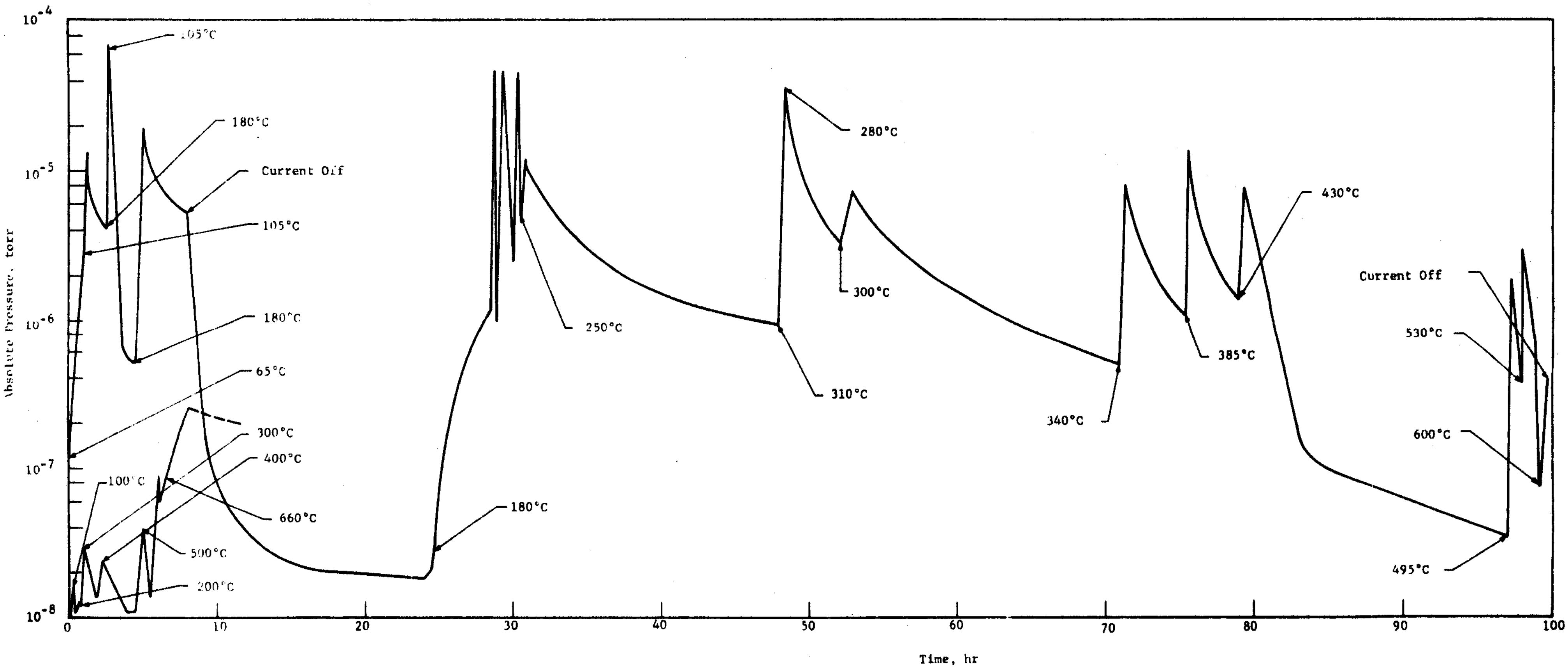

Fig. 16 - PUMPDOWN CURVES FOR OLIVINE POWDER

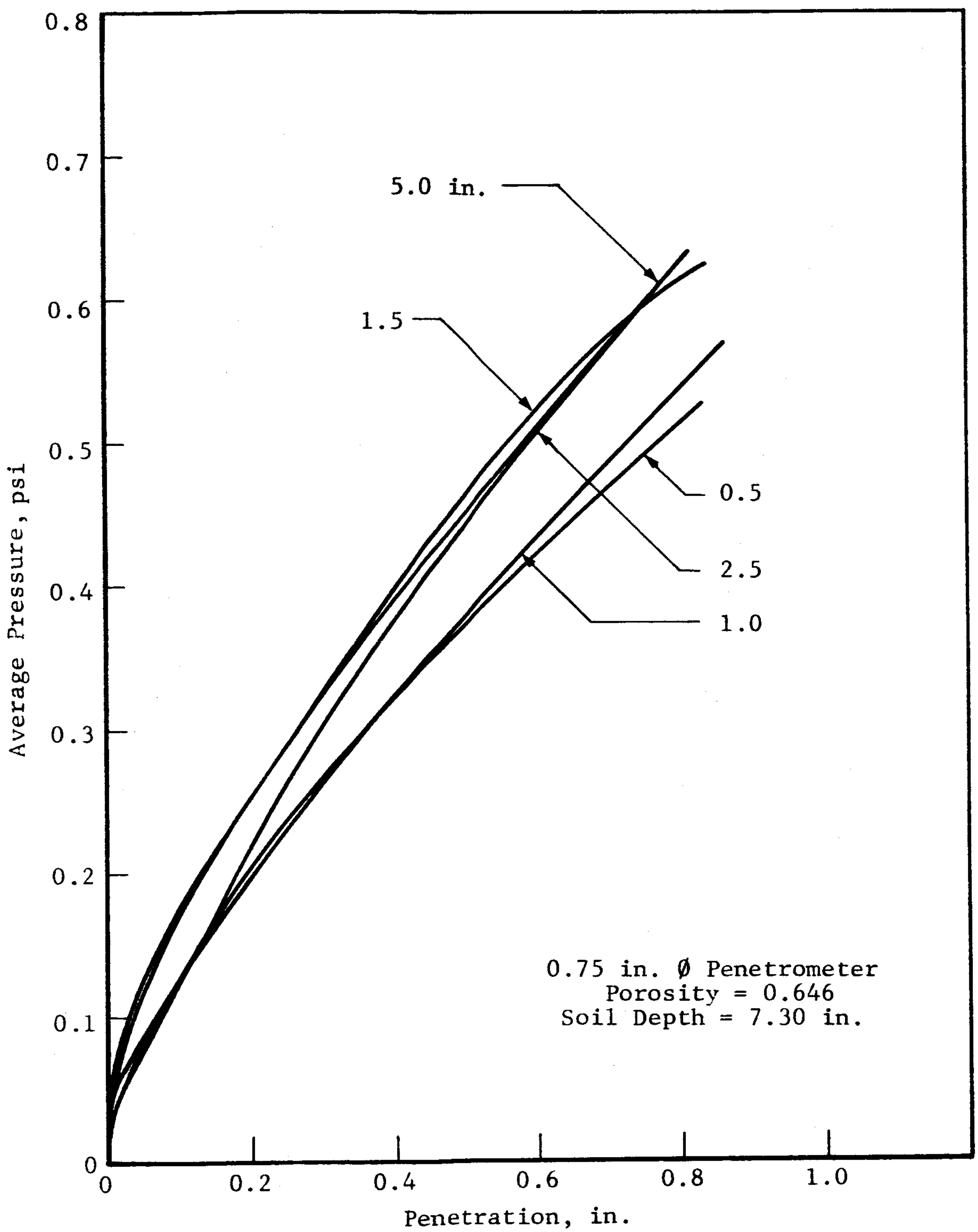

Fig. 17 - PENETRATION RESISTANCE AT VARIOUS EDGE DISTANCES

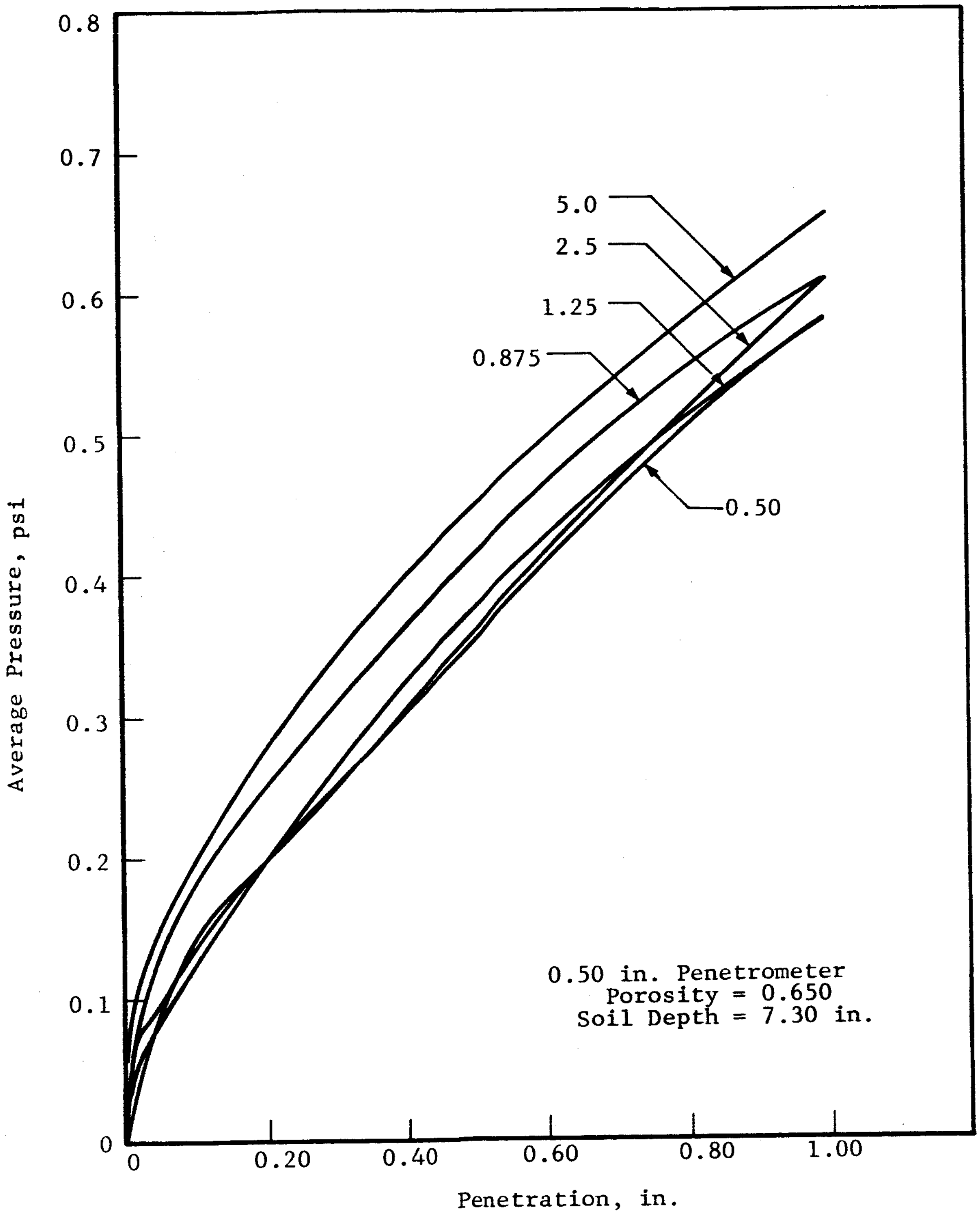

Fig. 18 - PENETRATION RESISTANCE FOR VARIOUS EDGE DISTANCES

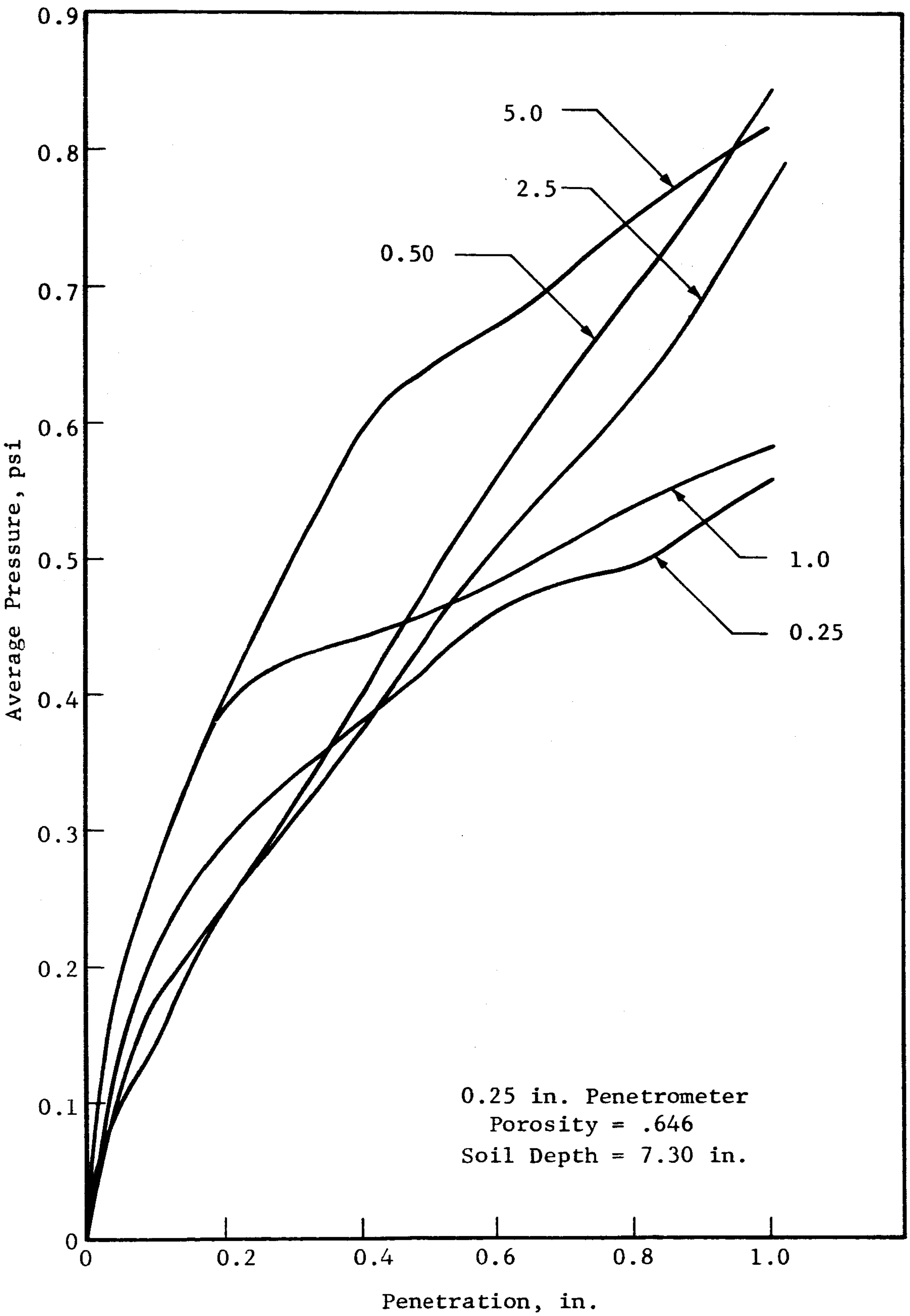

Fig. 19 - PENETRATION RESISTANCE FOR VARIOUS EDGE DISTANCES

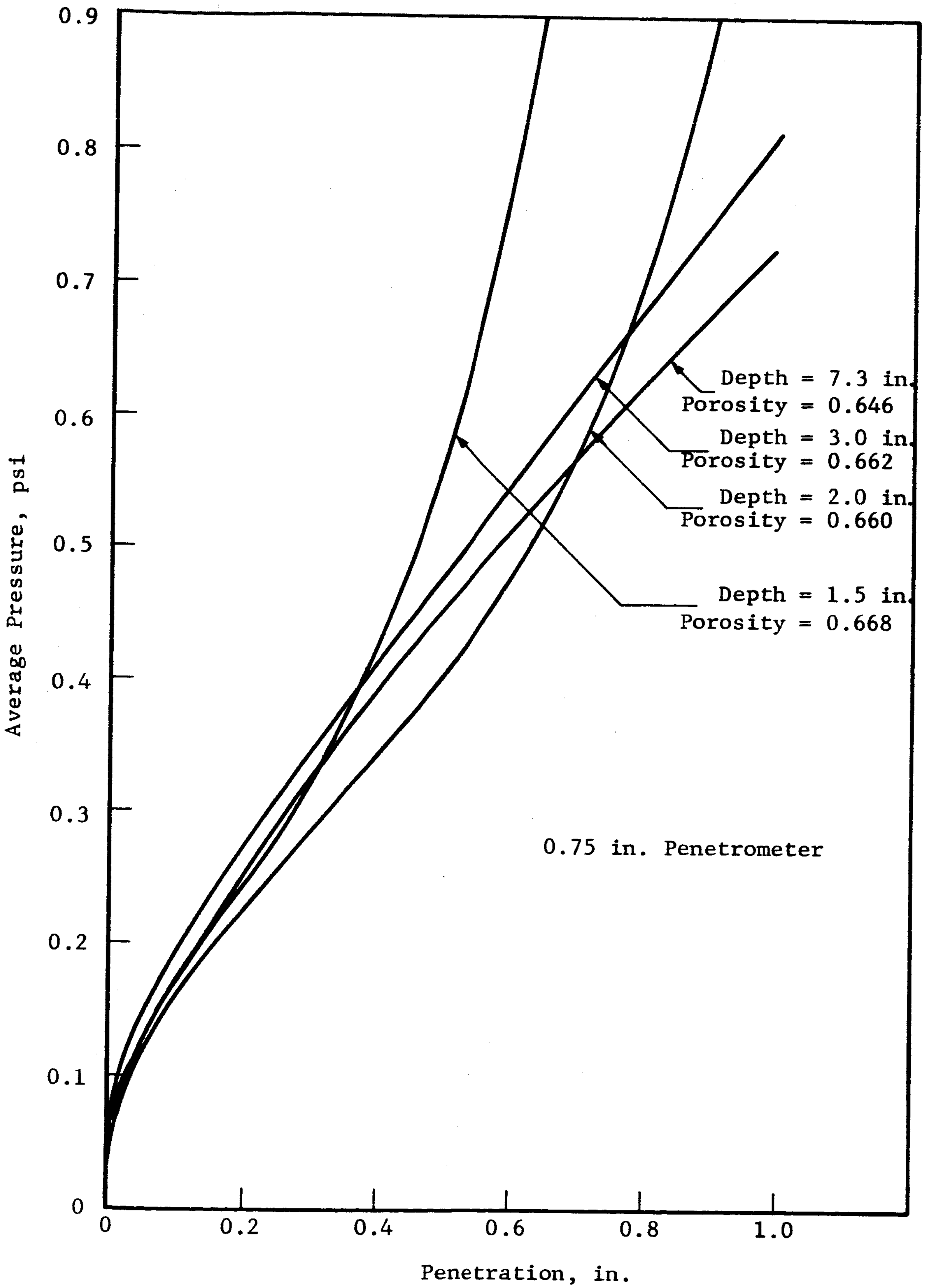

Fig. 20 - PENETRATION RESISTANCE FOR VARIOUS SOIL DEPTHS

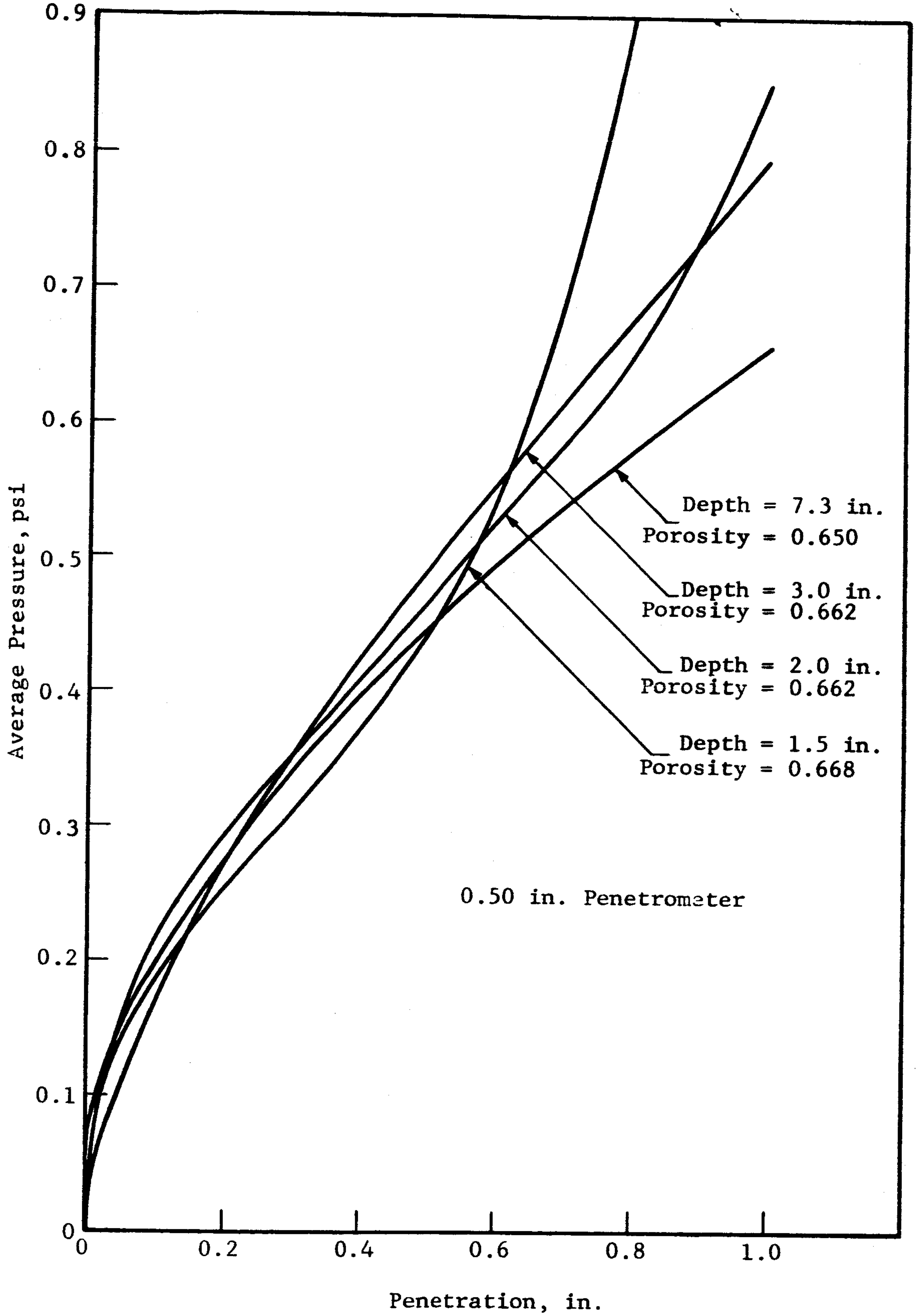

Fig. 21 - PENETRATION RESISTANCE FOR VARIOUS SOIL DEPTHS

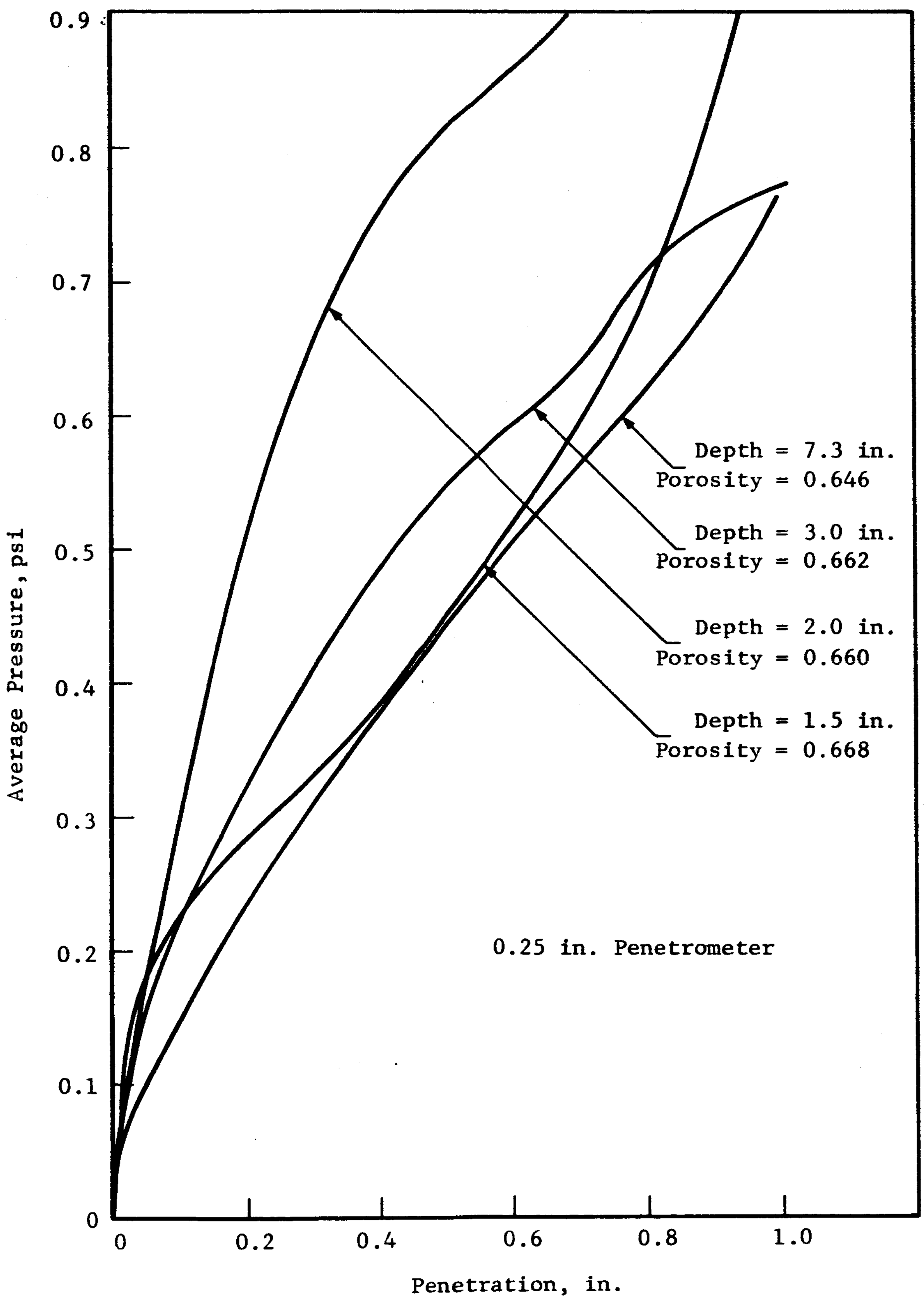

Fig. 22 - PENETRATION RESISTANCE FOR VARIOUS SOIL DEPTHS